I. M. Kowalski
J. Szarek
D. Zarzycki
A. Rymarczyk

Experimental scoliosis in the course of unilateral surface electrostimulation of the paravertebral muscles in rabbits: effects according to stimulation period

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I.M. Kowalski
Rehabilitation Department of the Regional
Rehabilitation Hospital for Children
in Ameryka, 11-015 Ameryka, Poland

J. Szarek
Department of Forensic and
Administration Veterinary Medicine,
University of Warmia and Mazury in
Olsztyn, Ul. Oczapowskiego 13,
10-717 Olsztyn, Poland

D. Zarzycki (✉) · A. Rymarczyk
Department of Pediatric Orthopaedics and
Rehabilitation Jagiellonian University,
College of Medicine, Ul. Balzera 15,
34-501 Zakopane, Poland
e-mail: klinika@zakopane.top.pl,
Tel.: +48-18-20-146-18

Abstract Scoliosis among children and adolescents is a persistent problem. Worldwide, it afflicts between 0.3 to 15.3% of the population. One of the treatment methods of this disorder is to administer lateral electrical surface stimulation (LESS) for 9 h/day; unfortunately, however, this results in side-effects. Improvements are therefore sought. The main aim of the study was to investigate the effects of the duration of LESS on scoliosis progression and to evaluate, qualitatively, any associated macroscopic effect on other internal organs. The length of the LESS period was based on the results of previous clinical trials in children. The experiment was performed on 13 developing rabbits (aged 3.5 months), divided into three groups: group 1, rabbits subsequently treated for 9 h/day ($n=5$); group 2, animals treated for 2 h/day ($n=5$); group 3, control rabbits without electrostimulation ($n=3$). Stimulation was carried out using an electric stimulator SCOL-2 according to the method modified by Kowalski. The animals were killed after

3 months and examined macroscopically, and their adrenal glands were dissected and weighed. The X-rays of the spine of the animals were taken to analyse spinal deformity. Macroscopic lesions in rabbits from groups 2 and 3 (control) were mostly absent. While there was considerable deviation in group 1, all the stress features were apparent. The enlargement of the adrenal glands observed in group 2 was significantly less marked than in group 1. The degree of scoliotic deformity (according to the Cobb method) ranged from 21° to 410° (mean, 31.2°) and from 23° to 330° (mean, 30°) in groups 1 and 2, respectively. LESS resulted in spinal deformity to a similar degree in the rabbits treated for either 9 or 2 h/day over a 3-month period. Short LESS therapy (2 h/day) significantly reduced detrimental effects associated with the treatment on internal organs of laboratory animals.

Keywords Electrical stimulation · Rabbit · Scoliosis

Introduction

The prevalence of scoliosis among children and teenagers in different countries worldwide varies from 0.3 to 15.3% [12, 15, 19, 23]. Over the past decade, there have been a number of reports in medical literature regarding advancements in lateral electrical surface stimulation (LESS) [7,

12, 13, 22] in treatment of scoliosis, also known as electrospinal orthosis (ESO) [1, 6], surface electrical stimulation (SES) [4] or transcutaneous electrical stimulation (TCES) [1]. LESS therapy has been used since the late 1970s, during which time direct electrostimulation with needle electrodes inserted into the paravertebral muscles was routinely performed [5]. In the 1980s, transcutaneous electrical stimulation replaced intramuscular electrodes [3]. This method

consisted of using electrodes attached to the skin which provoked tetanic contractions of the muscles through stimulation of the intradermal proprioceptors. The increased muscle tension occurs due to repeatedly firing a reflex arch in which stimulatory/inhibitory impulses from the supra-medullary nervous centres to the motor units in the stimulated muscles are further enhanced/suppressed. These continuing changes in the tension of the paravertebral muscles may decrease, or completely eliminate, the spinal deformity [2, 3, 7, 10, 16, 23]. Overnight stimulation regimens, applied for varying durations (1–4 months), have been used [1, 2, 6, 10, 18].

The main aim of the present study is to investigate the effects of the duration of LESS on scoliosis progression and to evaluate, qualitatively, any associated macroscopic morphological lesions to other internal organs. Of interest was the evaluation of therapeutic effects and any possible stress-related side-effects of the technique in any macroscopic lesions in different organs, particularly the adrenals, as determined by necropsy in the investigated rabbits.

An overall duration of this experiment (3 months) was designed based on the results of similar studies in cats [3], rats [9], primates [4], rabbits [12] and chicken [16, 17]. The length of the daily LESS therapy in the present study was based on the results of previous clinical trials in children. The estimated duration of short LESS therapy (2 h/day) was not associated with severe discomfort and/or trauma in children undergoing the treatment [13]. This calls the usual duration of the procedure (approx. 9 h/day) into question [1, 6, 7, 11]. The results of our clinical experiments showed that shortening daily stimulation to 2 h (due to stress, sleep disturbances and micturition) produces correction of idiopathic scoliosis by 4° according to Cobb if the initial scoliosis was below 25° [13]. The same result has been obtained after administering LESS for 9 h/day. The clinical relevance of the current study is mainly related to the beneficial effect of the shorter therapy in reducing macroscopic lesions and the possible role this may play in reducing stress. Experiments on animals were undertaken to verify our clinical findings. These suggest that the traditional electrostimulation for 9 h/day may have an influence on the enlargement of adrenal glands [14]. It may also explain the occurrence of side-effects (stress) observed during clinical treatment. We were interested in confirming the clinical observations by mean of laboratory trials on animals.

Materials and methods

The 13 male, pure-bred (New Zealand White), age-matched (born within 5 days) and clinically healthy rabbits used in the present study were kept indoors in a room with a controlled temperature (18°C) and humidity (70%). Each animal was placed in a metal cage (50×50×50 cm) and received dry feed and water *ad libitum*. A 30-day period was allowed for adaptation to the new environment. At the beginning of the treatment, the rabbits were aged approximately 3.5 months and weighed between 2000 and 2200 g.

The experiment consisted of the following procedures. A skin area of 15×6 cm in close proximity to and on the right side of the spine of the rabbits was clipped, and the hair was removed using a chemical depilator. Two electrodes (outer diameter, 20 mm) were attached to the skin about 2–3 cm laterally to the spine and 6–10 cm from each other using double-sided adhesive patches and were covered with an elastic bandage cuff. The electrical stimulator (SCOL-2, Elmech, Warsaw, Poland) was fitted in the leather case harnessed onto the back of the rabbits, as described previously [13]. The rabbits were randomly assigned to one of the three groups: group 1 ($n=5$), in which the rabbits were subsequently treated for 9 h/day; group 2 ($n=5$), in which the rabbits were treated for 2 h/day; and group 3 (control, $n=3$), in which animals were not electrostimulated, but the stimulating electrodes remained attached to the skin for the duration of the experiment.

The technical parameters of the stimulator (SCOL-2) were as follows: stimulus type: triangular, intermittent; stimulus pulse duration: 0.1–0.2 ms; stimulus series duration: 3.5–4.5 s; stimulus frequency and strength: 20–50 Hz and 8–15 mA; power supply: 9-V batteries (type 6F22). The electrodes and stimulators were checked daily, and batteries were replaced once a month. The growing hair was depilated two to three times a week. Three months after electrical stimulation began, the stimulators were removed. X-rays were taken of the spine of the rabbits in the ventro-dorsal exposure for later analysis of spinal deformity. The animals were killed, and macroscopic post-mortem examinations were performed. The adrenal glands were dissected and weighed. Differences in the mean mass of the adrenal glands between the treated rabbits and control animals were analysed by analysis of variance (ANOVA; Epistat, version 4.2, 1991). The results are given as mean±SD. A Student's *t* test was carried out to analyse the differences of the mean angle of scoliosis in the experimental animal groups.

Results

Preliminary analysis of the X-rays of the vertebrae adjacent to the stimulated region revealed the occurrence of experimental scoliosis seen on the side contralateral to the area where the stimulating electrodes were attached in rabbits from groups 1 and 2. These spinal deformations appeared to be permanent, as it was impossible to correct them by physical spine elongation.

The degree of the spinal deformity according to the Cobb method [21] ranged from 21° to 41° (mean, 31.2°) in rabbits in group 1 (Fig. 1) and from 23° to 33° (mean, 30.0) in animals in group 2 (Fig. 2) (Table 1). By means of the Student's *t* test, it was shown that the differences in mean values of Cobb's angle in the animals treated with LESS for 9 and 2 h daily were not statistically significant. The induced scoliosis was located between Th3 and Th8 or between Th2 and Th10, and the distal region of deformity was between Th9 and L3 and between Th9 and L4 in groups 1 and 2, respectively. The scoliosis was confined to 6–11 vertebrae (an average of 8) and to 7–12 vertebrae (an average of 9) in groups 1 and 2, respectively. In group 3 rabbits, scoliotic deformity was not observed (Fig. 3).

During the post-mortem examination, no overt effects were observed in the group 2 (2 h of electrostimulation/day) or group 3 (control) animals. In two of the five rabbits from group 1 (9 h of electrostimulation/day), hyperaemia of the liver was observed, and in one of these rabbits hy-

Fig.1 Anteroposterior radiograph of rabbit spine. Group 1: electrostimulation 9 h/day

Fig.2 Anteroposterior radiograph of rabbit spine. Group 2: electrostimulation 2 h/day

Table 1 Experimental angle of scoliosis in rabbits determined by the Cobb method

Group of rabbits	Experimental scoliosis			
	Before experiment		After experiment	
	Range	Mean	Range	Mean
LESS 9 h/day	0°–0°	0°	21°–41°	31.2°
LESS 2 h/day	0°–0°	0°	23°–33°	30.0°
Control	0°–0°	0°	0°–0°	0°

LESS, lateral electrical surface stimulation

peraemia of the kidneys was also seen. The two rabbits appeared to be cachectic, as judged by a relatively small increase in body mass determined at the end of the study and smaller amounts of subcutaneous and kidney fat tissue compared with the remaining animals in the same group and control rabbits. The average mass of both adrenal glands was 0.50 ± 0.09 , 0.42 ± 0.003 and 0.30 ± 0.009 g in

Fig.3 Anteroposterior radiograph of rabbit spine. Group 3: control without electrostimulation

groups 1, 2 and 3, respectively; groups 1 and 2 differed ($P < 0.01$) from group 3, and group 1 differed from group 2 ($P < 0.05$).

Discussion

In the present study, the shorter duration of muscular electrostimulation (2 h/day vs. 9 h/day), applied over 3 months, was associated with an ostensibly lower stress response, as evidenced by a difference in mean mass of the adrenal glands collected post-mortem from the rabbits. The spinal deformation seen in rabbits undergoing the shorter period of treatment was comparable to the deformity demonstrated in the rabbits treated for 9 h/day, suggesting that the prolonged stimulation is not essential for permanently altering the normal spinal configuration. Interestingly, the total number of vertebrae within the area encompassing the induced scoliosis was somewhat higher in group 2 (nine vertebrae) than in group 1 (eight vertebrae). This might be due to a more localised tetanic tension of the paravertebral muscles in group 1 rabbits. The probable reason for this occurrence was an increase in fatigue of stimulated paravertebral muscles caused by electrical impulses in the rabbits exposed to serial stimulation for the longer period of time.

The duration of the experiment causing spinal deformity in rabbits was established based on the work performed by Bigard et al. [4], Joe [9], Kin [12] and Machida et al. [16, 17], who suggested that electrical stimulation should be carried out for 1–4 months.

The spinal deformity located at the opposite side to the stimulated side observed in the experiment is similar to the effects reported by other authors [3, 4, 8, 9, 20]. Such deformation was found in monkeys by Bigard et al. [4], in rats by Joe [9], in rabbits by Sevastik et al. [20] and Herbert and Bobechko [8] (with a similar number of animals as in our experiment) and in cats by Axelgaard et al. [2].

In these cases, the resulting deformations were located in the breast segment. The maximum Cobb angle of spinal deformity in the group receiving stimulation for 9 h/day described by Axelgaard et al. [3] was 56°, whereas in the experiment of similar duration conducted by Joe [9], it was up to 28°. The maximum spinal deformity in our experiment was 41°, and the daily stimulation shortened to 2 h.

Detailed analysis of the muscular fibres of the paravertebral muscles and their metabolism by Bigard et al. [4] and Joe [9] indicates the temporary disorders caused by LESS. However, the results obtained by Kowalski [13] and Szarek et al. [22] indicate the opposite – permanent regressive changes in paravertebral muscles resulting from electrical stimulation for 9 h/day for a period of 3 months, but no such lesions after the application of LESS for 2 h/day.

Stress disorders in children and adolescents treated using the traditional stimulation duration (9 h/day) have been reported by Kahanowitz et al. [10], Kahanowitz and Weiser [11], Bradford et al. [6] and Durham [7]. The above-mentioned authors described the patients' stress as resulting from the LESS. By shortening the duration of LESS to 2 h/day in our clinical practice, we were able to eliminate the side-effects in children and adolescents and achieved similar therapeutic effects of idiopathic scoliosis correction. In our investigations [13], the effectiveness of the LESS method was observed as measured by scoliosis angle improvement: in 75.5% of patients with initial angles below 250, a decrease by 4° with 2 h LESS per day; in 74.0% of patients with an initial angle below 25°, a decrease by 3° with 9 h of LESS per day.

Research performed by Kahanowitz [10] revealed that LESS was effective in 63–70% of patients, in whom the progression of scoliosis was either decreased or inhibited. Positive results in 72–75% of patients were achieved by Anciaux, Bobechko and Herbert [1, 5], while Kahanowitz in another study [11] observed such success in 80–85%

of patients. The best results of applying LESS were observed by Axelgaard: 93–97% [2, 3].

Most authors observed that LESS is effective if the scoliosis angle is below 300° or 250° [1, 2, 3, 5, 10, 11]. They revealed an improvement of 4° if the curvature angle was 270° or less, and of 7.6° if it was 250° or less.

Bobechko and Herbert [5] suggested that further analytical studies into the shortening of daily electrostimulation time in idiopathic scoliosis treatment would be justified; however, there have been no results to date. This paper aims to justify the shortening of strenuous daily therapy to 2 h. Our described experimental findings are clinically relevant and may have important implications regarding the development of appropriate electrical stimulation regimes for patients with idiopathic scoliosis; they justify a shortened duration of the therapy.

Conclusions

It was concluded that either LESS therapy for 9 h or 2 h/day over a period of 3 months caused similar degree of spinal deformity. The shorter LESS therapy (2 h/day) considerably reduced detrimental effects associated with the treatment on muscles and internal organs of laboratory animals. Shortening the time of daily application of electrical stimulation in patients with scoliosis is a worthwhile consideration in medical practice. Much more research is needed in this area to relate different variables such as age, body mass and general condition to the projected overall duration (in months) of the LESS procedure.

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